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Detection of QPO in the Rising Phase of the Outburst of Black-Hole GX339-4

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Abstract:** GX339-4 is a Galactic black hole binary. Galactic transient black hole candidates (BHCs) are very interesting objects to study in X-rays because they exhibit rapid evolutions in their temporal and spectral properties during outbursts. During an outburst, it has been noticed that onset of monotonically increasing /decreasing nature of QPO frequency during rising / declining phases of the outburst always accompanies by sudden rise in ARR, accretion rate ratio i.e., in halo rates as compared to the disk rate. We report on the timing behavior using Rossi X-ray Timing Explorer (RXTE) data of the black hole system GX339-4 during its 2010 outburst. We analyze archival data of this object from the PCA instrument on board RXTE and study the evolution of QPO frequencies during the rising phase of the outburst. We successfully fit the variation of QPO frequency using the Gaussian model. We report detection of variable quasi-periodic oscillation (QPO) of frequencies 1.01Hz, 1.35Hz and 2.4Hz.These QPO were observed on 28th January 2010, 29th January 2010 and, 5th February 2010.

1. INTRODUCTION

In our Galaxy, the brightest X-ray emission originating from point sources is produced by binary systems harboring a black hole or neutron star that is accreting material from a (sub) solar mass companion star. Galactic transient black hole candidates (BHCs) are the most fascinating objects to study in X-ray domain since these sources exhibit evolutions in their timing and spectral properties during their outbursts. Several attempts [14],[1],[19],[17] were made for a thorough study on the temporal and spectral evolutions of the transient black hole (BH) binaries during their outbursts .Galactic transient black hole candidates (BHCs) exhibit rapid evolutions in their temporal and spectral properties during outbursts. In past two decades, especially after launch of *Rossi X-ray Timing Explorer* (RXTE), our understanding of black hole binaries have progressed significantly. However, real progress in extracting physical parameters was hampered due to lack of appropriate data analysis tools. For instance, fitting a spectrum with a black body and power law components (so-called disk plus power-law, or compost models in XSPEC) tells us that there is a multicolor soft photon source such as a Shakura-Sunyaev standard disk [22] and a so-called Compton cloud [25],[26] which is a collection of free electrons with certain optical depth and temperature. However, cause of formation of standard disk, nature and origin of Compton cloud or cause of a specific spectral state remains missing. GX339–4 was found by the X–ray satellite OSO–7 in 1971.Since it was similar to Cygnus X–1 in terms of the feature of spectrum and short time variations, it was suggested as a black hole candidate. This source is one of the best studied BHCs at X rays and gamma rays by various instruments LAC.

As mentioned above, many authors have studied GX339-4 is a bright and well studied X-ray binary. It is usually classified as a black hole candidate and in many aspects is very similar to Cyg X-1 [29].

GX339−4 (4U 1658−48) is one of the best-studied Galactic BH candidates over a wide range of wavelengths. The source is a classic X-ray transient. It is usually found in the active, low/hard flux state, but is known to undergo dramatic changes on month–year time spans, showing a broad range of X-ray states from 'quiescence', to the 'very high' state [31],[6]. Such changes are accompanied by strong modulations in its radio [3], and optical [13] properties. The source has proven to be key for the discovery and elucidation of several important aspects of XRB behavior. It was one of the first to show clear evidence of the existence of an inner accretion disc in the X-ray low/hard state (Miller et al. 2006). It is the prototype source for defining an important relationship between the radio and X-ray fluxes of XRBs [3].

In this paper we present timing study of GX339-4 during outburst of 2010 and report the detection of QPO with variable frequencies varies from 1 Hz to 2.5Hz

2. OBSERVATION AND DATA ANALYSIS

RXTE was launched on 1995 December 31 and the timing studies of celestial X-ray sources was its main objective. It made great contributions to our understanding of high energy astrophysics by means of its unrivaled timing resolution. Almost all the X-ray sources in the sky are variable i.e. their intensity changes with time. The intensity changes can be highly periodic, quasi periodic or sometimes totally periodic. Time scale of such variation ranges from few mill-seconds to tens of years. The plot of the power of individual component as a function of frequency is known as Power Density spectrum. Data will be analyzed by using appropriate operating system soft ware heasoft and different models. First the standard step for methodology to quantify variability is to compute the power, spectrum that is the amplitude squared of the Fourier transform of the light curve. The power spectra is expected to give information about characteristic frequencies of the system which might show up either as spectral breaks or as near Gaussian peaks, i.e. Quasi-Periodic oscillations (QPO). A QPO is identified by performing a power spectrum of the time series of the X-rays. A periodic pulsation appears in the power spectrum as a peak of power at exactly one frequency or more than one frequency. The QPO phenomenon promises to help astronomers understand the innermost regions of accretion disks and the masses, radii, and spin periods of white dwarfs, neutron stars, and black holes. Data will be sampled by analyzing the ASM (All Sky Monitor) light curve. If this curve has outburst then it will appropriate for timing and spectral studies. In any outburst, accreting matter is very large so we can obtain a sharp peak in ASM light curve, which gives many physical parameters. Data will be collected by different satellites like ASCA, ROSAT, CHANDRA, ASTROSA, XMM-Newton, SUZAKU, SWIFT etc. These satellites collect data from different sources, which are available at the NASA's site. In our investigation we collect data by RXTE.

We present timing analysis results of publicly available archival data from RXTE Proportional Counter Array (PCA) instrument for entire 2010 outburst of GX339-4.We used the publicly available data of GX339-4 observations with RXTE/PCA. Our sample includes 26 observations. The power spectra of GX339–4 in the low spectral state feature a prominent QPO peak which frequency varies typically between 1 Hz and 2.5 Hz (Fig.1). The heasoft 6.11 version of the software package was used to analyze the PCA data. We extract data from the most stable and well calibrated proportional counter unit 2 (PCU2; all the three layers are co-added). For the timing analysis, we use the PCA standard 2 data with a maximum timing resolution of 125μs.

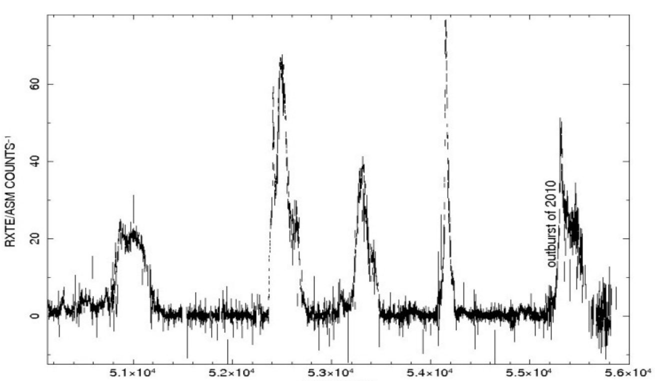

Fig. 1 ASM one-day averaged light curve of the GX339-4 from 1996 February (MJD 50133) to 2012 January 01 (MJD 55927). During entire observing period of RXTE, many major outbursts were detected in the ASM light curve. RXTE/PCA observations during 2010 outburst were analyzed to investigate the QPO features in the pulsar.

The ASM was sensitive in 1.5-12 keV energy range [19]. The PCA, which was consisting of five Xenon filled proportional counter detectors, was sensitive in 2-60 keV energy range. The effective area, energy resolution and time resolution of PCA were 6500 cm^2 at 6 keV, 18 % at 6 keV and 1 s, respectively. A detailed description of the PCA instrument can be found in paper by Jahoda [8].The third instrument, HEXTE was operating in 15-250 keV energy range [19]. We used standard 1 mode data, which provided binned data with a time resolution of 0.125 s, as all 256 channels were combined into one, to calculate the light curve and pulse periods. Figure 1 represents the full RXTE-ASM curve from the beginning of the RXTE mission in 1996 to 2012

We used data from all the PCA observations for our timing analysis during the 2010 outbursts (as marked in figure 1). There were a total of 26 RXTE/PCA observations during 2010 outburst. We used PCA data from above observations to study the evolution of QPO in this pulsar. Standard 1 mode data with a time resolution of 0.125 s were used in the present analysis. Data reduction was carried out by using the software package FTOOLS whereas data analysis was done by using the Heasoft package (version 6.11).Observation detail with date, Modified Julian Days (MJD), duration of observation, exposure of observation, the PCUs on during the observation and averaged light curve counts with error are shown in table 1, 2,. Using the standard 1 mode PCA data, we extracted light curves with a time resolution of 0.125 s from all the RXTE pointed observations during the 2010 outburst.

Table 1: IDs which have no QPO

Table:1

Obs id	Obs date	Pcu on	Mjd	Exposur	Duration
95409-01-02-01	18/01/10	2,3	55214	2400	3292
95409-01-02-02	21/01/10	1,2	55217	2958	4024
95409-01-03-01	27/01/10	2	55223	1912	2641
95409-01-04-00	29/01/10	2,3	55225	3690	5603
95409-01-04-01	31/01/10	1,2	55227	2422	2759
95409-01-04-02	02/02/10	2,3	55229	2847	3334
95409-01-04-03	04/02/10	1,2,3	55231	2163	2486
95409-01-05-00	05/02/00	2	55232	1908	3914
95409-01-05-03	08/02/10	2,3	55235	3414	6307
95409-01-05-05	11/02/10	1,2	55238	1947	2281
95409-01-06-00	12/02/10	0,2	55239	2584	4873
95409-01-06-02	17/02/10	2,4	55244	2129	3902
95409-01-07-02	24/02/10	0,2	55251	2450	3306
95409-01-08-02	02/03/10	1,2	55257	2111	2802
95409-01-08-03	04/03/10	1,2	55259	3433	4020
95409-01-09-05	05/03/10	4,2	55260	1193	3292
95409-01-10-00	12/03/10	2,4	55267	2671	3196
95409-01-10-01	13/03/10	2,4	55268	1953	2476
95409-01-10-03	15/03/10	2	55270	3548	5881
95409-01-10-04	16/03/10	2	55271	3546	3961
95409-01-10-05	17/03/10	1,2	55272	2948	6028
95409-01-10-06	18/03/10	2,4	55273	5723	9107
95409-01-12-01	28/03/10	2	55283	26143	2757

Table2: Three IDs which have QPO.

Obs	Obs	Qpo frq	Unc	Imodel	Sq root Imodel
95409-01-03-06	28/01/10	1.01Hz	2.7	6.98	2.64
95409-01-04-00	29/01/10	2.4Hz	2.7	2.25	1.5
95409-01-04-06	03/02/10	1.35Hz	2.7	6.62	2.57

Figure and Table:

Out of a total of 26 RXTE observations, we found the presence of QPOs in 3 observations (as shown in table no. 2). The log of observations is given in Table 1, 2. The variable QPO between 1.01 Hz and 2.5Hz (as shown in table no.2) seen in the GX339-4. Figure 2, 3& 4 show the representative PDS for the outburst of 2010 for observation IDs 95409-01-03-06, 95409-01-04-00 and 95409-01-04-06 respectively.

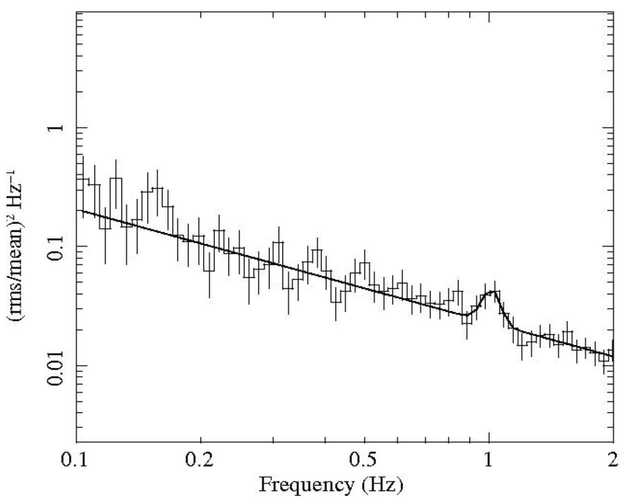

Fig. 2 Representative PDS showing QPO for observation ID 95409-01-03-06(MJD 55261)

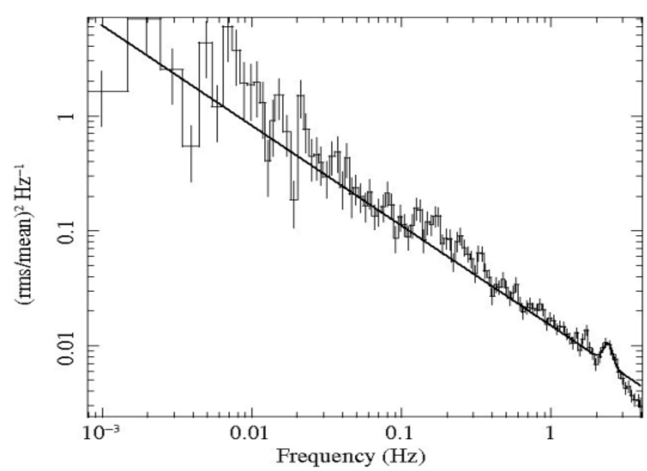

Fig. 3 Representative PDS showing QPO for observation ID 95409-01-04-00 (MJD 55286)

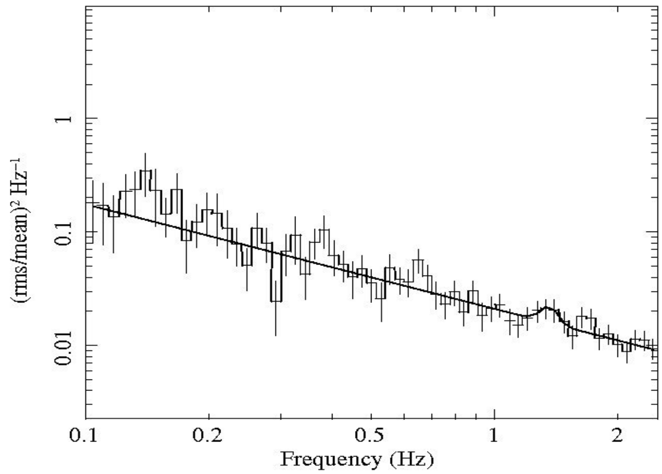

Fig. 4 Representative PDS showing QPO for observation ID 95409-01-04-06 (MJD 55292)

3. DISCUSSIONS

Studying temporal variability and finding QPOs in power density spectra (PDS) is an important aspect for any black hole candidate (BHC). It is observed (mainly at hard and hard-intermediate spectral states) that the frequencies of QPOs are seen to evolve with time. LFQPOs are reported extensively in the literature, although there is some uncertainty about the origin of these QPOs. So far, many models are introduced to explain the origin of this important temporal feature of BHCs, such as trapped oscillations and disko-seismology [10] oscillations of warped disks [23] accretion-ejection instability at the inner radius of the Keplerian disk [20] global disk oscillations [27] and perturbations inside a Keplerian disk [28] propagating mass accretion rate fluctuations in hotter inner disk flow [7] and oscillations from a transition layer in between the disk and Comptonized flow [24] However, none of these models attempt to explain long duration continuous observations and the evolutions of QPOs during the outburst phases. Of transient BHCs. One satisfactory model namely shock oscillation model (SOM) by Chakrabarti and his collaborators [16] shows that the oscillation of X-ray intensity could be due to the oscillation of the post-shock (Comptonizing) region. According to SOM, shock wave oscillates either because of resonance (where the cooling time scale of the flow is comparable to the in fall time scale; [16] or because the Rankine-Hugoniot condition is not satisfied [21] to form a steady shock. The QPO frequency is inversely proportional to the in fall time (*tin f all*) in the post-shock region. The Propagating Oscillatory Shock (POS) model, which can successfully explain the evolutions of QPO frequency, is nothing but a special case (time varying form) of SOM. As explained in our earlier papers on POS model [2], [5], [17] during the rising phase, the shock moves towards the black hole and during the declining phase it moves away from the black hole. We now present the results of the evolution of QPO frequency observed in rising phases of the outburst of

2010. We generated power-density spectrum (PDS) from each of the light curves by using the FTOOLs package. We found that the1.61ms regular pulsations of the pulsar and its harmonics were present in the PDS obtained for all the PCA observations. Apart from these pulsations and corresponding harmonics, the PDS from some RXTE/PCA observations during the outburst of the pulsar. QPOs of frequencies 1.01Hz, 1.35Hz and 2.4 Hz (as shown in table no. 2) in the BH GX339-4 are detected.

4. CONCLUSIONS

In this paper, we performed timing analysis using RXTE observation of the BHC GX339-4 during the outbursts of 2010.Temporal analysis performed with RXTE/PCA observations showed X-ray pulsations. Using Gaussian model to fit and analyze the PDS of X-ray pulsars and investigate their random variability, we have discovered variable QPOs between ~1.01 and 2.5 Hz of centroid frequency are in excellent agreement with the predictions of the BFM. We also calculate the area of QPOs.

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